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# In-Service Elementary Teachers' Understanding of Magnetism Concepts Before and After Non-Traditional Instruction

*The authors provide a descriptive study of in-service elementary teachers' understanding of magnetism concepts and confidence in their understanding of those concepts before and after non-traditional instruction that utilizes instructional activities from Physics by Inquiry.*

## Introduction

Magnetism is a topic frequently studied in elementary schools (Toleman, 1998). Since magnetism is a popular topic and is included in national science education standards (American Association for the Advancement of Science, 2003; National Research Council, 1996), it might be assumed that elementary teachers have a good understanding of this topic and that elementary students develop a good understanding of fundamental magnetism concepts. Unfortunately, evidence suggests that magnetism concepts are poorly understood across a broad range of potential learners (Atwood, Christopher & McNall, 2007; Constantinou, Raftopoulos, & Spanoudis, 2001; Finley, 1986; Hickey & Schibeci, 1999). The lack of successful teaching and learning of magnetism concepts that occurs at the elementary level may be partly due to deficiencies in elementary science textbooks (Barrow, 1990) for elementary students and elementary science methods and materials textbooks (Barrow, 2000) for teachers. However, ineffective science content courses in teacher preparation are likely to be a much larger problem (McDermott, 1991; McDermott, Heron, Shaffer, & Stetzer, 2006). There is a clearly identified need to improve instruction on magnetism, and elementary science teacher education is a logical place to focus. A study of pre-service (Atwood & Christopher, 2007) teachers has revealed a poor understanding of basic magnetism concepts, and traditional survey science courses may be doing little to improve that situation. The documentation of inadequate understanding of standards-based magnetism concepts by elementary students and teachers is an important start to understanding the nature and magnitude of this problem, but it is also necessary to address the lack of conceptual understanding of elementary teachers.

**The idea that understanding is domain-specific is central to thinking about conceptual understanding and change.**

## Theoretical Framework

The following considerations were used to identify characteristics of instruction likely to be associated with the desired impact:

1. The goal of the instruction is to facilitate teachers' construction of conceptual understanding of basic magnetism concepts.
2. Traditional instruction has failed to result in the desired understanding, so it is unsuitable for the study (McDermott, 1991; McDermott, Heron, Shaffer, & Stetzer, 2006).
3. Minimally guided, non-traditional instruction has been strongly criticized recently and is unlikely to result in the desired understanding (Kirschner, Sweller, & Clark, 2006; Mayer, 2004).

4. Non-traditional investigative instruction that is judiciously structured and scaffolded and consistent with the intentional conceptual change literature has shown great promise and should be utilized in the study (Beeth, 1998; Niaz, 1995; Nussbaum & Novick, 1982; Vosniadou, 2003, 2007).

For some time, the science education community has shown considerable support for teaching for understanding (American Association for the Advancement of Science, 2003; Gallagher, 2000; Gardner & Boix-Mansilla, 1994; National Research Council, 1996; Prawat, 1989; Wildey & Wallace, 1995). During roughly the same period, it has been well documented that diverse populations of children and adults lack a scientific understanding of many fundamental science concepts across the biological, earth, and physical sciences (Atwood & Christopher, 2007; Bar, 1989; Barman & Griffiths, 1995; Baxter, 1989; Brody & Koch, 1990; Driver, Guesne, & Tiberghien, 1985; Duit, 1984, 2004; Duit & Treagust, 1995; Krall, Christopher, & Atwood, 2009; Osborn & Cosgrove, 1983; Schoon, 1992; Trundle, Atwood & Christopher, 2002).

The pervasive lack of conceptual understanding has been partially attributed to the failure of traditional instruction, a term that seems to be a broad umbrella for a variety of presentation modes. Textbooks and lectures have historically been the most popular modes for presenting information, but these methods typically do not use the collection and analysis of data as a basis for generating explanations. Although computers and other technology are increasingly used as presentation modes, as well as for more creative purposes, the basic approaches behind the instructional methods often remain largely unaltered.

**Regardless of when they are formed, non-scientific conceptions can be organized into a durable, theory-like framework that has explanatory capacity and is resistant to change.**

Minimally guided, non-traditional instructional approaches have been utilized as alternatives to traditional presentation modes, but their effectiveness has recently been strongly criticized (Kirschner, Sweller, & Clark, 2006; Mayer, 2004). Critics have tended to paint all efforts to utilize discovery, constructivist, inquiry-based, and problem-solving approaches with the same broad brush. They have argued that minimally guided instructional approaches fail, because they place a heavy burden on students' cognitive processing that prevents students from processing novel information.

However, non-traditional instruction consistent with conceptual change theory is judiciously structured and scaffolded yet still investigative in nature (Beeth, 1998; Champagne, Gunstone, & Klopfer, 1985; Cosgrove & Osborn, 1985; Hewson & Hewson, 1983, 1984; Jackson, Dukerich, & Hestenes, 2008; Niaz, 1995; Nussbaum & Novick, 1982; Osborn & Wittrock, 1983; Smith, Blakessie, & Anderson, 1993; Vosniadou, 2003; Weaver, 1998). The work of Vosniadou (1991, 2002, 2003, 2007) has been particularly useful in exploring the ways in which conceptual change theory should inform instruction, perhaps because her views have been influenced by personal research on non-scientific conceptions (Vosniadou, 2003; Vosniadou & Brewer, 1994).

The idea that understanding is domain-specific is central to thinking about conceptual understanding and change (Carey, 1985). Further, although understanding is constructed internally by an individual, the process may be influenced externally by a number of factors. Socio-cultural influences, such as formal schooling, can be among the most important external factors (Hatano & Inagaki, 2003). Conceptions formed prior to formal schooling tend to be naïve and non-scientific. Regardless of when they are formed, non-scientific conceptions can be organized into a durable, theory-like framework that has explanatory capacity and is resistant to change. Becoming metacognitively aware of how one's understanding compares with the accepted scientific understanding and being motivated to adopt the scientific understanding, seem crucial for the radical restructuring that is sometimes required (Vosniadou, 2003, 2007). To achieve intentional conceptual change, it is necessary to go beyond active learning. Sinatra and Pintrich described this process as "the goal-directed and conscious initiation and regulation of cognitive, metacognitive and motivational processes to bring about a change in knowledge" (2003, p. 6). Although instruction has a critical role to play in helping students to achieve the conceptual change that must take place in order to gain understanding of fundamental science concepts, it seems highly unlikely that either a traditional presentation mode of instruction or minimally guided non-traditional modes of instruction will create the conditions needed for intentional conceptual change to occur.

## The Instruction

McDermott (1991) and others have described the inadequacies of traditional presentation-mode science survey instruction for teachers (McDermott et al., 2006). McDermott has led a group in the development of instructional materials, called *Physics by Inquiry* (McDermott, 1996), that appear to be strongly aligned with the instructional characteristics needed to promote intentional conceptual change. Further, use of *Physics by Inquiry* instructional materials has been associated with sharply increased performance among pre-service elementary teachers studying several other science topics, such as moon phases (Trundle, Atwood & Christopher, 2002) and force and motion concepts (Arts, 2006). Comparable positive results have been found for in-service middle school teachers' study of light phenomena (Atwood, Christopher & McNall, 2006). The *Physics by Inquiry* materials are structured to encourage students to take responsibility for their own active learning. This promotes metacognitive processing, because students must compare the explanations they have previously held in their conceptual frameworks with explanations that explain the data they generate through investigations. In this way, *Physics by Inquiry* instructional materials about magnetism support both empirical data and intentional conceptual change theory.

In the present study, instruction on magnetism was provided as part of a one-week physical science institute for in-service elementary teachers.

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Approximately five hours of the 30 available for instruction during the week were devoted to magnetism, and the remainder was used to address other physical science topics. *Physics by Inquiry* was the source of activity ideas and instructional strategies. It should be noted that the investigators selected only a fraction of the activities and materials available in the magnetism section of *Physics by Inquiry*. Due to the time limitation, activities and materials judged to be most fundamental to the schools' K-4 content standards were selected. While participating in these activities, teachers work in small groups to complete investigations, make and discuss observations, and arrive at conclusions.

In one activity, participants were given two bar magnets (identified as such) and a tray of objects made from a variety of materials. They were asked to explore the character of any interaction between the magnets and between the magnets and other objects. Then, they were led to classify the objects into three categories on the basis of the observed magnetic interactions. The three categories were later identified as magnets, ferromagnetic materials, and non-magnetic materials. Participants prepared an evidence-based procedure for confidently determining whether a magnet was included among a group of objects. Next, they studied in more detail the interactions between the parts (ends and middle) of two bar magnets with each other and also with similarly shaped ferromagnetic materials. This led to the introduction of the idea of magnetic poles, and participants then discussed methods of finding the poles and identifying them as north-seeking or south-seeking. The teachers then participated in activities that allowed them to locate the positions of the two poles on a variety of familiar magnets. Next, they observed and described the behavior of magnetic compasses. Participants were also given a magnetic model of the earth, and they discussed how magnetic compass needles behave in relation to the model. At this point, each group was issued a paper clip and a ruler and instructed to use those materials to develop a procedure for comparing the strength of two magnets. The groups then used their procedure to order the strength of the poles of a number of magnets that had different sizes and shapes. Finally, the small groups explored the analogy between a bar magnet and a stack of flat, rectangular "refrigerator" magnets (with the poles on the faces). They identified the pole locations and types of poles for a stack, and they compared the behavior of stacks of varying sizes.

In summary, this non-traditional, guided inquiry instruction frequently engaged the in-service teachers in making systematic observations and engaging in interpretive discussions of their own observations. They also prepared responses to three *checks,* which were written conclusions based on previous observations and responses to challenging application questions. Each check was completed in written form by each individual, discussed in a small group, and then defended during a discussion with an instructor. This constructivist design encouraged participants to maintain a high degree of awareness of their own thinking and understanding as they mentally processed a steady inflow of observations and made conjectures. As suggested previously, instruction with these characteristics has a high potential for facilitating intentional conceptual change (Bereiter & Scardamalia, 1989; Hennessy, 2003).

## Research Questions

The central research question for this descriptive study is: How does the conceptual understanding of selected magnetism concepts compare before and after in-service elementary teachers complete non-traditional instruction from *Physics by Inquiry*? A secondary research question is: How does the confidence that in-service elementary teachers have in responding to assessment tasks on magnetism compare before and after completing non-traditional instruction from *Physics by Inquiry*?

### Procedures and methodology

The 18 elementary teachers in the non-random sample self-selected into a one-week physical science institute. The teachers were from four rural school districts in central Appalachia. Oliver (2007) has described the difficulty of defining rural in an era of greatly reduced isolation due to the internet and interstate highways. We use the rural school district description here for communities that are heavily dependent on agriculture in their economies and lack a town of more than 5,000. In addition to the approximately five hours of instruction provided on magnetism concepts, during the remaining 25 hours of instructional time, physical properties, light phenomena and force and motion were also addressed. Considerably more instructional time was devoted to light phenomena and force and motion than magnetism, because it was assumed that magnetism was more likely to have been regularly taught by elementary teachers. Given that, it was reasoned teachers were more likely to have learned what they needed about magnetism than light phenomena and force and motion. Additionally, prior to determining the institute topics, instructional supervisors in the region expressed the view that local teachers were better prepared to teach magnetism than light phenomena and force and motion.

Five multiple-choice tasks with popular non-scientific conceptions embedded in the distracter options (Hestenes, Wells, & Swackhamer, 1992) were a major source of data in addressing the central research question. In addition, teachers were asked to provide a brief, written justification or explanation for each multiple-choice selection. These supporting statements were expected to provide insight into the reasoning used to make the multiple-choice selections. Finally, the teachers rated their confidence in the correctness of each answer using a five-point scale. The confidence level descriptions and corresponding numerical ratings were as follows:

1. Highly confident
2. Somewhat confident
3. Neutral in confidence
4. Somewhat lacking confidence
5. No confidence

The confidence data were used to address the secondary research question. Since magnetism is a popular topic in elementary schools, it was thought that the teachers might be confident in responding to magnetism questions. The teachers were given instructions for generating and using a code on all assessment forms to insure anonymity and minimize anxiety while allowing pre-test and post-test matching of individuals' scores. The assessment tasks were administered, along with tasks addressing the other physical science topics, during the beginning and closing hour of the institute.

**If teachers have not been adequately prepared to teach fundamental concepts about magnets and the behavior of magnets, there are important implications for both pre-service and in-service teacher education.**

## Results and Discussion

The results are presented and discussed by multiple-choice task. A representative sample of participants' explanations of multiple-choice option selections is included in the discussion. The self-reported confidence rating is located in parentheses immediately after each explanation. For each task, the multiple-choice pre-test data that showed the frequency with which each option was selected were cross-classified by the post-test data. This arrangement facilitates the analysis of changes in multiple-choice responses from pre-test to post-test. In order to give the reader an understanding of the advantages of this arrangement, Table 1 shows the data arranged in this way for Task 1. In the interest of conserving space, similar tables that were used in the analysis of Tasks 2-5 are not included here, but interesting changes in responses from pre-test to post-test are described in the text. Table 2 provides a summary of the data corresponding to the multiple-choice and supporting explanation or justification for each of the five tasks. The confidence data for all five tasks have been placed in Table 3 to help communicate the shifts in confidence that occurred.

**Table 1:** Task 1 Comparison of pre-/post-test multiple-choice selections by in-service teachers.

Results reported as frequencies, except as noted

| | | Post | | | | | | Pre-Totals | Pre-Totals |
|---|---|---|---|---|---|---|---|---|---|
| | | **A*** | **B** | **C** | **D** | **E** | **Omit** | **as *f*** | **as %** |
| | **A*** | 7 | 0 | 0 | 0 | 0 | 0 | 7 | 38.9 |
| | **B** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | **C** | 4 | 0 | 2 | 0 | 0 | 0 | 6 | 33.3 |
| | **D** | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 16.7 |
| **Pre-** | **E** | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 11.1 |
| | **Omit** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| **Post- Totals as *f*** | | 16 | 0 | 2 | 0 | 0 | 0 | 18 | |
| **Post- Totals as %** | | 88.9 | 0.0 | 11.1 | 0.0 | 0.0 | 0.0 | | 100 |

Note. The '*' marks the correct letter choice for the task.

Using magnets to attach a variety of objects to refrigerator doors is a common practice in homes. Task 1 provided an opportunity to show an understanding of the science involved. Table 1 and Table 2 provide a summary of multiple-choice results for Task 1, and Table 3 includes the confidence levels associated with each response.

Teachers who understand that very few materials, including iron, are ferromagnetic and will interact with a magnet can demonstrate that understanding by choosing option A. Table 1 reveals that only 7 of 18 (39%) participants selected A on the pre-test, but 16 of 18 (89%) did so on the post-test. Option C was the most popular distracter option on the pre-test, as it was selected by six (33%) teachers. Only two teachers selected this option on the post-test, and these were the only persons who failed to select the correct response. Refrigerator doors require little effort to open and close, and this may have led to the mistaken conclusion that a lightweight metal, such as aluminum, was used in the doors. However, if the teachers had ever had the experience of testing several different known metals, including iron and aluminum, it seems likely that option A would have been the preferred choice on the pre-test. Because it is known that a popular and strongly held non-scientific conception is that magnets attract most metals (Hickey & Schibeci, 1999), the opportunity to test several labeled metals, including aluminum, and discuss the results was provided during the instruction. It appears that experience was sufficient for four of the six participants who selected C on the pre-test.

**Figure 1:** Task 1 assesses interactions between magnets and ferromagnetic materials.

1. The most likely reason magnets stick to refrigerator doors is because they are interacting with
   A. iron in the doors.
   B. the plastic or ceramic coating on the doors.
   C. a lightweight metal, such as aluminum, in the doors.
   D. a heavy metal, such as lead, in the doors.
   E. electric charge on the refrigerator doors.

Examination of the pre-test explanations or justifications showed that two of the seven teachers who selected the correct answer simply stated that "magnets stick to iron" (2, 4), two wrote "magnets are attracted to iron" (2, 4), and a fifth explained why the other four options were not correct. Another correct pre-test responder provided no written explanation (3), and still another explained, "magnets have to attract to metal or iron" (3). The latter response appears to represent a false positive, a correct response based on a non-scientific reason. False positives represent an important limitation of forced-choice

**Table 2:** Pre-test and post-test data showing frequencies and percents of correct multiple-choice (MC) responses and correct multiple-choice responses adequately supported by explanation or justification

| | Correct Pre- | | | | Correct Post- | | | |
|---|---|---|---|---|---|---|---|---|
| | MC Only | | MC and Support | | MC Only | | MC and Support | |
| Task | f | % | f | % | f | % | f | % |
| 1 | 7 | 38.9 | 5 | 27.8 | 16 | 88.9 | 13 | 72.2 |
| 2 | 14 | 77.8 | 9 | 50.0 | 17 | 94.4 | 13 | 72.2 |
| 3 | 5 | 27.8 | 1 | 5.6 | 15 | 83.3 | 10 | 55.6 |
| 4 | 12 | 66.7 | 7 | 38.9 | 18 | 100.0 | 14 | 77.8 |
| 5 | 11 | 61.7 | 2 | 11.1 | 9 | 50.0 | 6 | 33.3 |
| Totals | 49 | 54.4 | 24 | 27.8 | 75 | 83.3 | 56 | 62.2 |

**Table 3:** Tasks 1-5 summary of magnetism pre- and post-test confidence for in-service elementary teachers

| Response Frequencies from 1, Highly Confident to 5, No Confidence | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre- | | | | | | Post- | | | | | |
| Task | 1 | 2 | 3 | 4 | 5 | Total | 1 | 2 | 3 | 4 | 5 | Total |
| 1 | 0 | 6 | 5 | 6 | 1 | 18 | 13 | 5 | 0 | 0 | 0 | 18 |
| 2 | 2 | 8 | 4 | 3 | 1 | 18 | 10 | 7 | 1 | 0 | 0 | 18 |
| 3 | 0 | 3 | 4 | 7 | 4 | 18 | 9 | 4 | 2 | 1 | 2 | 18 |
| 4 | 1 | 5 | 5 | 2 | 5 | 18 | 14 | 4 | 0 | 0 | 0 | 18 |
| 5 | 3 | 3 | 6 | 2 | 4 | 18 | 13 | 5 | 0 | 0 | 0 | 18 |

tasks (Trundle, Atwood & Christopher, 2002). Thus, as shown in Table 2, on the pre-test only five of 18 teachers both selected the correct response and provided a satisfactory statement in support of their selection. The average confidence level for the five participants who selected the correct answer to Task 1 on the pre-test and provided a scientifically correct justification was 2.8, a neutral level.

On the post-test, 16 of 18 teachers (88.9%) selected the correct response. However, only 13 of the 16 who selected the correct response also provided a scientific explanation (see Table 2). These 13 teachers had an average confidence level of 1.1. Of the remaining three correct multiple-choice responders, one stated that "magnets are attracted to metals containing lead" (1), one provided no explanation and selected a confidence level of 1, and one admitted to making a "guess" (1). The first and last of these three participants are assumed to represent false positives, and it is possible that the response with no justifying explanation was also a false positive. The fact that the seven teachers who selected the correct multiple-choice response on the pre-test also did so on the post-test is viewed as a positive result. In fact, Table 1 reveals that all movement from one response option to another was positive, from a non-scientific option to the scientific option.

One of the two teachers who selected option C on the post-test explained, "the door must have some type of metal to attract the magnet" (2). This explanation is essentially unchanged from the pre-test and is interpreted as confirmation of a firmly held non-scientific conception. The second teacher explained, "some metals do not attract magnets" (2) but apparently thought that aluminum does.

In Table 3, note that no teacher selected a confidence level of one on the pre-test and only six (33%) selected a two. In comparison, on the post-test 13 persons selected a confidence level of one and the other five selected a two. Overall performance on Task 1 is much improved on the post-test. This is true for selecting the correct multiple-choice response, providing scientific explanations in support of correct responses, and expressing greater confidence in correct selections and explanations. It is interesting to note that even those who failed to support a correct multiple-choice response with a satisfactory explanation were very confident on the post-test.

Task 2 was used to probe participants' understanding that the needle of a magnetic compass aligns to point approximately geographic north and south.

**Figure 2:** Task 2 assesses an understanding of the interaction of the Earth's magnetic field with a compass.

2. You may use a magnetic compass to find your way,
   A. since the compass needle will always point in the direction you are facing.
   B. during the day but not during the night.
   C. since the compass needle aligns in a north/south direction.
   D. if there aren't too many trees or mountains nearby.
   E. because compass needles don't move.

As shown in Table 2, 14 of the 18 participants (78%) selected the correct answer, C, on the pre-test and 17 participants (94%) did so on the post-test. Analysis of the pre-test results shows that nine of the 14 who made the correct multiple-choice selection gave an explanation that the compass needle always points north, and four of those nine added correct information about magnetic poles in their explanations. However, two of the remaining five gave no explanation (with confidence levels of 3 and 5), and responses by the other three consisted of "not sure" (4), "I think" (2), and "guess" (4). Eight of the nine teachers who gave a satisfactory explanation in support of a correct multiple-choice selection on the pre-test selected one of the top two confidence levels and the other chose the neutral level (3). A low confidence level paired with no substantive explanation supports suspicion, but does not confirm, that the correct multiple-choice selection resulted from an understanding that is not strongly held, or from guessing. Thirteen of the 17 who selected the correct multiple-choice response on the post-test also provided adequate scientific explanations. Representative explanations include "the needle of the compass is magnetic and the north end of the needle will point to the north pole that has a south magnetic pull" (2) and "the N needle always points to the N geographical pole (S magnetic pole)" (1).

On the pre-test, three persons selected option A for Task 2. Although this may be viewed by persons working in the sciences as a curious choice, it is a perspective not uncommonly encountered by the authors in working with both pre-service and in-service elementary teachers. In the present study, the pre-test explanations provided in support of this choice were: "compasses show you what direction you are traveling in" (4), "based on the true north/south the needle will point the way you are facing" (3), and "a compass tells you the direction you are facing" (2). On the post-test, the three persons who had selected option A on the pre-test joined the 14 persons who selected the correct response on both the pre-test and post-test. All three gave satisfactory supporting explanations on the post-test, including "the needle of a compass is magnetic and the north end of the needle will point to the north pole that has a south magnetic pull" (2). Again, all of the movement from one multiple-choice option to another on Task 2 was positive.

In Table 3 note that participating teachers showed more confidence in their pre-test responses to Task 2 than for any other task, as ten teachers chose levels one or two. Confidence increased in post-test responses with 17 of 18 participants selecting confidence levels one or two. The only person who selected an incorrect response on the post-test provided no explanation for it and chose the neutral confidence level.

Bar magnets are frequently used in elementary classrooms. Task 3 (Figure 3) provided an opportunity for the teachers to consider the validity of five statements about bar magnets and the behavior of bar magnets.

A review of the data in Table 2 shows that pre-test performance on Task 3 was the weakest of the set. Only five participants (25%) selected the correct answer, D. The confidence data in Table 3 for Task 3, consistent with the multiple-choice results, also are the lowest of the set. For the five teachers who selected the correct multiple-choice option on the pre-test, the explanations provided were: "process of elimination" (4), "guess" (3), "guess" (4), "has plus and minus charged ends" (4), and "they will repel if turned correctly" (4). Thus, four of the five statements suggest the correct responses on the multiple-choice task may have been false positives, because only one teacher both selected the correct response and provided a satisfactory supporting explanation. Note also that one confidence level was neutral and the other four were below the neutral level, including for the one teacher whose explanation is consistent with a scientific understanding.

**Figure 3:** Task 3 assesses the expected understanding of the properties and behavior of bar magnets.

3. A bar magnet
   A. has the strongest magnetic effect in the middle of the bar.
   B. interacts with all metallic objects.
   C. will not influence a magnetic compass.
   D. can repel any other magnet.
   E. interacts with heavy metals like lead, brass, and gold.

Each distracter option was attractive to between 11 and 28% of the sample. Four participants selected option A, which was the idea that a bar magnet has the strongest magnetic effect in the middle of the bar. The explanations included an idea the investigators had not encountered previously, which was that magnetic fields are "strongest where the N/S come together" (3), as well as several previously encountered explanations such as "a process of elimination, I think" (3), "guess" (5), and "I am not sure; I used an educated guess" (5). Note the neutral to low confidence levels associated with these statements.

On the pre-test results for other Task 3 distracters, four teachers selected option B, which indicates a bar magnet interacts with all metallic objects. The varied supporting statements provided were "B seemed like the only one that could be true" (4), "a magnet interacts with metal no matter what shape" (2), "a bar magnet has two charges, plus and minus" (2), and "?" (4). Two of the three persons who selected option C also apparently had little understanding of the properties of bar magnets. One of the two did not provide an explanation (confidence level 4), and the other wrote, "I guessed" (5). The third person who selected C was somewhat confident and explained that "the opposite poles will react and similar poles will not" (2). The two persons who selected option E wrote "attracts to all metals" (3) and "guess" (5). Note that the former respondent expressed neutral confidence while the latter expressed no confidence. Both Tasks 1 and 3 reveal the attractiveness of the non-scientific conception that magnets attract many different metals.

The post-test selection of the correct response on Task 3 by 15 of 18 (83%) participants is viewed as a very favorable result when compared with the pre-test data. Further, 10 of the 15 also provided a satisfactory supporting statement. The five persons who selected the correct response on the pre-test also did so on the post-test. In addition, three of four teachers who had selected option A, all of the persons who had selected options B or C, and one of the two teachers who had selected option E moved to the correct response on the post-test. Two of the three persons who selected an incorrect post-test response had made a different incorrect response on the pre-test. Neither offered an explanation on pre-test or post-test to justify their selections. Perhaps neither held a scientific nor specific non-scientific conception before instruction and that status had not changed after instruction. The teacher who stayed with option E showed little confidence in the justification provided on the post-test, which was that "the magnet will interact with other magnets" (4). This explanation was an improvement over "attracts all metals" (3), which was the pre-test explanation.

**Figure 4:** Task 4 assesses understanding of properties of magnets, specifically, that magnets have a N and S pole and strength of a magnet cannot be predicted by its size or shape.

4. Which of the following statements about bar, horseshoe, and round refrigerator magnets is most accurate?
   A. Large magnets are stronger than small magnets.
   B. Magnets have a N-pole and a S-pole.
   C. Horseshoe magnets are stronger than bar magnets which contain the same amount of material.
   D. Round magnets have only a N-pole or only a S-pole.
   E. A bar magnet will pick up more paper clips than a round refrigerator magnet.

Task 4 probes for understanding of magnets, including the concept that magnets have North-seeking and South-seeking poles and the fact that the strength of magnets cannot be predicted by their size or shape. Table 2 shows that 12 teachers selected the correct response on the pre-test and the remaining six teachers joined them on the post-test. Although only 7 of the 12 correct pre-test multiple-choice responses were supported with a satisfactory explanation, 14 of 18 correct responses were adequately supported on the post-test. Option C was the most popular distracter on the pre-test. Two of the four persons who selected it admitted to guessing and reported confidence levels of five. Another seemed to be responding to limited first-hand experience in explaining, "it just seemed stronger" (3), and the fourth teacher concluded, perhaps based on the appearance of the two shapes, "has 2X force on an object" (5), but expressed no confidence in the response. It is encouraging that option D was not selected by anyone. One of the 12 correct responders on the pre-test offered no explanation (3) and a second admitted to guessing (5). Two others simply indicated they had heard that statement before (2,2). The eight statements that adequately supported the scientific conception included "magnets have an N and an S pole regardless of size" (3) and "magnets have an N and an S pole regardless of shape" (3).

The increase in correct multiple-choice responses from 12 to 18, pre-test to post-test, for Task 4 was accompanied by a strong increase in confidence. Table 3 shows that only six teachers reported an initial confidence level of one or two on the pre-test, but all 18 participants did so on the post-test. Interestingly, three persons who offered no attempt at an explanation and the one person who admitted to guessing all reported the top confidence level. Among the 14 satisfactory supporting explanations, two teachers wrote, “all magnets have N and S poles, regardless of size or shape” (1,1), and a third wrote, “to date all magnets have a north and south pole. Even if a north end is broken in two, the opposite end of the N becomes the south end” (1).

In Task 5 (Figure 5), participants can show understanding that the North pole of a bar magnet attracts not only the South pole of another magnet, but also attracts objects containing a ferromagnetic material, such as iron. Option D represents this response, and on the pre-test 11 of the 18 participants (61%) selected D. However, only three of the 11 gave an explanation that included two possible causes for the attraction. Of these three, only two made appropriate supporting comments, such as “opposites attract and iron attracts to magnets” (1). However, the third teacher wrote, “Metal will stick to the bar magnet and so will the S pole of another magnet” (1), which again supports the non-scientific conception that all metals are attracted to magnets, and the person was highly confident of that response. Of the other eight participants who chose the correct multiple-choice option on the pre-test, seven offered very brief statements that would be justification for selecting option B, such as “N attracts S” (3). The other respondent admitted to guessing. It seems likely that all of these teachers had observed a magnet attract objects not identified as magnets. However, the ferromagnetic material concept does not seem to be a functional component of most participants’ conceptual framework for magnetism. Surprisingly, the confidence of these nine teachers ranged equally from top to bottom. Three were highly or somewhat confident, three were neutral in confidence, and three were somewhat lacking confidence or expressed no confidence.

Three participants (17%) chose B on the pre-test, which stated that attraction between opposite magnetic poles was “for sure” the reason that the identified magnet would be attracted to an unidentified object. One participant who chose B explained “opposites attract” (2), another “guessed” (5), and the third explained that “opposite poles attract as the electrons will align/bond” (2). Of the total of 18 participants, 14 (11 of whom selected D and 3 of whom selected B) indicated via multiple-choice selections on the pre-test that opposite magnetic poles attract. However, as noted, only a few explanations addressed the issue correctly and fully by invoking the type of evidence that might be gained through simple experiments. Finally, of the four participants who chose incorrect responses A, C, or E, only one (the one who selected option C) wrote an explanation, which was that “opposite poles repel each other” (4). The four participants who chose A, C, or E expressed neutral to low confidence.

The post-test multiple-choice results for Task 5 are both puzzling and disappointing. Nine teachers, compared to 11 on the pre-test, selected the correct answer (D). It is interesting that five of 11 teachers who selected the correct response on the pre-test migrated to option B on the post-test. Further, this is the only one of the five tasks for which movement from a correct multiple-choice response to an incorrect response occurred from the pre-test to the post-test. Migration to B also occurred from responses A and C. Could it be that participants were eager to complete the assessment tasks during the closing event of the institute and simply selected the option they considered to be the first plausible response? Note that all 18 participants selected either B or D on the post-test. Examination of the explanations provided by the nine persons who selected D showed that six participants clearly indicated that the N end of the object in the task could be an opposite pole, S, or the object could be made of a ferromagnetic material, such as iron. A representative supporting statement was: “The north pole of a magnet would attract the south pole of another magnet or any ferromagnetic material” (1). So, although the number of participants who selected the correct multiple-choice response dropped from 11 to nine from pre-test to post-test, there was an increase from two to six in the number of persons who chose the correct response and also provided a scientific explanation that identified both opposite poles and ferromagnetic material as plausible explanations for the attraction described in the test item. The small percentage of participants who both addressed the issue correctly and fully supported their response with evidence of the type that might be gained through simple experiments seems to reflect a deficiency in the instruction provided. One of the remaining three who selected the correct response on the post-test provided only the opposite pole explanation, another admitted to guessing, and the third did not offer any explanation. Of the nine teachers who selected option B, eight provided the opposite poles attract explanation and one provided no explanation. Looking at Table 3, confidence reported in multiple-choice selections and supporting explanations moved from an average of 3.1 on the pre-test, a neutral level, to a high level average of 1.3 on the post-test.

For the five multiple-choice tasks combined, 49 of 90 responses (54.4%) were correct on the pre-test, and 75 of 90 responses (83.3%) were correct on the post-test. Further, multiple-choice responses were supported with satisfactory explanations for 25 of the 49 correct multiple-choice responses on the pre-test and for 56 of 75 correct multiple-choice responses on the post-test. Therefore, 25 of 90 multiple-choice responses (27.8%) on the pre-test and 56 of 90 (62.2%) on the post-test were both correct and cross-validated by explanations. These results were accompanied by sharply increased levels of reported confidence, as demonstrated by the finding that 34 of 90 ratings were 1 or 2 on pre-test compared to 84 of 90 on the post-test.

**Figure 5:** Task 5 assesses understanding that an unlike pole and ferromagnetic material are attracted to a magnetic pole.

5. Consider the diagram below

The N-pole of a bar magnet is brought near end A of an object that looks very similar to the bar magnet in shape, size, and color. If end A of the object is attracted to the N-pole of the magnet, you could

A. be sure that the object is another bar magnet and A is the N-pole.
B. be sure that the object is another bar magnet and A is the S-pole.
C. conclude that the object is either a bar magnet and A is the N-pole or the object is not a magnet but contains iron or a material that magnetically behaves like iron.
D. conclude that the object is either a bar magnet and A is the S-pole or the object is not a magnet but contains iron or a material that magnetically behaves like iron.
E. not make any of the conclusions in A. – D.

## Conclusions and Implications

The results of this analysis indicate that the pre-institute level of the teachers' understanding of magnetism concepts had been overestimated, and, consequently, the extent and duration of the instruction needed was underestimated. Based on the results, it is concluded that the in-service elementary teachers in this sample had not previously received adequate content preparation to teach a rich unit on fundamental concepts of magnets and the behavior of magnets. Following completion of the short, non-traditional instructional intervention that was developed to be highly consistent with intentional conceptual change theory, the status of the group's conceptual understanding was much stronger but still in need of further improvement. Low confidence in multiple-choice responses and supporting explanations was frequently reported by teachers on the pre-test, even in instances when a correct response was selected. On the post-test, teacher confidence was much higher across all five tasks. Ideally, teachers would both provide evidence of strong science content preparation and be highly confident in their understanding of the content. The non-traditional instruction provided in this study seems to be associated with improvement in conceptual understanding and confidence in understanding. We conclude that the quantity of instruction provided should have been more extensive. The expectation that more extensive instruction with the same characteristics would be associated with evidence of better conceptual understanding is supported by a study of 178 pre-service elementary teachers who completed approximately 11 hours of magnetism instruction from *Physics by Inquiry*. Their pre-test performance on these same five tasks tended to be a little lower than the performance of the in-service teachers in the present study, but their post-test performance was essentially the same as found in the present study, except for Task 5. Only 41.6% of the pre-service group selected the correct response on pre-test for Task 5, but 84.8% did so on the post-test (Atwood & Christopher, 2007). In the present study, 61.1% selected the correct response on the pre-test, but only 50% did so on the post-test.

If teachers have not been adequately prepared to teach fundamental concepts about magnets and the behavior of magnets, there are important implications for both pre-service and in-service teacher education. First, it is likely that this topic is not being adequately addressed in pre-service teacher education programs, possibly because the topic is viewed as easier than other physical science topics. Alternatively, this might just be indicative of the more general problem of inadequate coursework in science for prospective elementary teachers (McDermott, 1991; McDermott et al., 2006; Trundle, Atwood & Christopher, 2002). In any case, a modest investment in appropriate instruction is associated with impressive gains in conceptual understanding (Atwood, Christopher, Combs & Roland, 2008). Additionally, the results of this study indicate that any assumption made by instructional supervisors or professional development providers that in-service elementary teachers are relatively well prepared to teach fundamental concepts about magnets and the behavior of magnets should be seriously questioned. It seems likely that the popular task of having children use magnets to test several objects in a classroom is not a highly productive activity in terms of concept development. Teachers leading these activities may not understand that all of the metallic objects interacting with a magnet almost certainly do so because they contain iron. (The odds of common metallic objects having nickel or cobalt in them are very small.) If teachers lack this knowledge, they are unlikely to help their students develop fundamental understanding by making sure a variety of non-ferromagnetic metals are identified and tested, followed by appropriate, sense-making discussions and explanations.

In addition, the results of this study suggest that teachers often lack experience determining where the magnetic effect of several magnets of varying shape and size is strongest (i.e., where the poles are located). By engaging in this process, teachers should determine that all magnets have two and only two magnetic poles and that like magnetic poles repel and unlike poles attract. Further, experience with large and small magnets of the same shape should be structured so it becomes clear that the strength of a magnet cannot be reliably predicted by size. Controlling size to the extent possible, while varying shape of magnets in appropriate investigations also seems to be needed for teachers to understand that the strength of a magnet cannot be reliably predicted by shape. Finally, more direct experiences and sense-making discussions about the effects that earth's magnetic field has on compass needles and other magnets seem to be needed for teachers. Clearly, these recommendations are not aligned with either traditional presentation mode instruction or with minimally-guided, non-traditional instruction. However, they are aligned with non-traditional instruction that is consistent with intentional conceptual change theory (Vosniadou, 1991, 2003, 2007).

Results of the present study could be used to help establish professional development priorities for in-service teachers and inform professional development plans that target magnetism and the behavior of magnets with instruction designed to promote conceptual change (Vosniadou, 1991, 2003, 2007). The results also could be used for formative purposes by higher education faculty who are committed to providing effective science programming for pre-service elementary teachers. The evaluation tasks fully described here could be used to determine whether other groups of pre-service or in-service teachers have essentially the same needs as were documented in the present study. Based on this study and literature cited earlier that documents the pervasiveness of the problem in the general population, we would predict this is not an isolated problem for either pre-service or in-service teachers.

Finally, we view one-on-one clinical interviews using props and probes as the most effective method of assessing the conceptual understanding of individuals (Trundle, Atwood & Christopher, 2002). However, in-service teachers are very wary of efforts to assess their content knowledge. This barrier, combined with a lack of sufficient time and other resources, make interviews of individual in-service teachers problematic and very difficult for instructional supervisors and other professional development providers to utilize. When supported by explanations and confidence ratings, multiple-choice tasks with popular non-scientific conceptions embedded in the distracter options, offer a viable alternative. The administration time is reasonable, and the data obtained can be very useful. Further, when a coding system is used to assure anonymity, teachers are comfortable and respond well to this mode of assessment.

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